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Can the sneutrino be the lightest supersymmetric particle ?

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Abstract

Within the framework of the constrained Minimal Supersymmetric extension of the Standard Model we show that recent LEP I limits on the invisible Z width exclude the possibility that the lightest sparticle is the sneutrino.

Introduction

We investigate the constrained ‘Minimal Supersymmetric extension of the Standard Model’ (MSSM) as used for example by the LEP collaborations [?]. It assumes Grand Unification, no extra CP violation, a common scalar mass scale, etc., so that out of more than 100 possible new constants in a general SUSY model only the following free parameters are left:

- m_0 = Universal scalar mass at the GUT scale
- $M_2 = SU(2)$ gaugino mass at the electroweak scale
- μ = Higgs(ino) mass parameter (elw. scale)
- $\tan\beta$ = Ratio of higgs vacuum expectation values (elw. scale)

The additional parameters A_0 and m_A are not important here. The quantum number R Parity is assumed to be conserved, so that the lightest supersymmetric particle (LSP) is stable. Cosmological arguments together with limits on abundances of atoms with anomalous charge over mass ratios require that the LSP carries neither colour nor electrical charge [?].

In the MSSM only two particles fulfil these constraints: The lightest neutralino, $\tilde{\chi}_1^0$, and the sneutrino $\tilde{\nu}$. Note that the common scalar mass m_0 implies that the three sneutrinos $\tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau$ are degenerate in mass, and we do not distinguish between them. A third LSP candidate is the gravitino, but in the constrained MSSM it is assumed to be heavier than the other SUSY particles, as predicted in supergravity models.

A priori it is not clear which one is the LSP. Since the existing upper mass limit for the sneutrino is better than for the lightest neutralino [?], many physicists concentrate on the hypothesis LSP = $\tilde{\chi}_1^0$. In this paper we investigate for which SUSY parameters the sneutrino plays the role of the LSP, and to what extent this possibility is ruled out by existing experimental bounds.

Limit on sneutrino mass

First we analyse the experimental bounds; it turns out that the limit obtained in e^+e^- collision experiments with centre of mass energies around the Z pole is most stringent [?].

The LEP I measurements of the Z properties allow to constrain the non Standard Model contributions to the invisible Z width to [?]

$$\Delta\Gamma_{\text{inv}} < 2.0 \text{ MeV} \quad 95\% \text{ CL} \quad , \quad (1)$$

assuming 3 light neutrino species. ‘Invisible’ decay channels are those, for which a substantial fraction (typ. 50% or more) of the energy carried by the final state particles is unseen in the detector and which are inconsistent with fermion pair production. Also sneutrino pairs might be produced in Z decays. If they act as LSP they are stable and undetected, thus contributing to Γ_{inv} . For the conclusions of this paper it is sufficient to discuss this case.

The sneutrino contribution to the invisible Z width is given by [?]:

$$\Delta\Gamma_{\text{inv}}^{\tilde{\nu}} = 3 \cdot \frac{1}{2} \cdot \left[1 - \left(\frac{2m_{\tilde{\nu}}}{m_Z} \right)^2 \right]^{3/2} \cdot \Gamma_{\text{inv}}^\nu \quad (2)$$

Here $\Gamma_{\text{inv}}^\nu = 167 \text{ MeV}$ is the neutrino contribution for one family. The factor 3 stands for the 3 families, $\frac{1}{2}$ results from the different spins of neutrinos and sneutrinos, and the term in brackets containing the sneutrino mass describes the kinematical suppression.

The experimental upper limit (1) can be converted into a sneutrino mass limit of

$$m_{\tilde{\nu}}^{LSP} > 44.6 \text{ GeV} \quad 95\% \text{ CL} \quad (3)$$

This bound improves the older limit of 43.1 GeV [?, ?].

It should be noted that our limit holds also in the more general case that either $\tilde{\nu}$ **or** $\tilde{\chi}_1^0$ act as the LSP. In the latter case the sneutrino will decay. If it is long lived, it escapes detection. If it is short lived the two dominant decay modes are neutrino plus neutralino and lepton plus chargino [?]. In the first case all or a large fraction of the energy escapes undetected. The second case is already ruled out from the lower limit on the chargino mass of $m_Z/2$, derived from the **total** Z width measured at LEP I [?].

Sneutrino-LSP in the MSSM

Now we turn to the sparticle masses as predicted in the constrained MSSM and investigate if we can set a theoretical upper limit on $m_{\tilde{\nu}}$.

To be the LSP the sneutrino mass must in particular fulfil the two relations

$$m_{\tilde{\nu}} < m_{\tilde{e}_R} \quad (4)$$

$$m_{\tilde{\nu}} < m_{\tilde{\chi}_1^0} \quad (5)$$

which are **not** true in large regions of the MSSM parameter space. Note that $m_{\tilde{e}_L} > m_{\tilde{e}_R}$ is always fulfilled. The charged sleptons $\tilde{\mu}$ and $\tilde{\tau}$ are heavier than \tilde{e}_R (with the stau possibly making an exception, if mixing is large; this would lead to the additional constraint $m_{\tilde{\nu}} < m_{\tilde{\tau}}$, yielding an even better sneutrino mass limit than the one presented below).

To understand the first relation (4) we calculate the two slepton masses using the approximate formulae given in [?]:

$$m_{\tilde{\nu}}^2 = m_0^2 - 0.5 m_Z^2 \frac{\tan^2 \beta - 1}{\tan^2 \beta + 1} + 0.80 M_2^2 \quad (6)$$

$$m_{\tilde{e}_R}^2 - m_e^2 = m_0^2 + \sin^2 \theta_W m_Z^2 \frac{\tan^2 \beta - 1}{\tan^2 \beta + 1} + 0.22 M_2^2 \quad (7)$$

The second term on the right hand side is due to quartic sfermion-higgs couplings. The term proportional to M_2^2 describes the running of the masses from the GUT scale to the electroweak scale.

Thus (4) is fulfilled if

$$\frac{\tan^2 \beta - 1}{\tan^2 \beta + 1} > 0.79 \frac{M_2^2}{m_Z^2} \quad (8)$$

using $\sin^2 \theta_W = 0.23$ and neglecting the electron mass. Since the left hand side is smaller than 1, we find in particular

$$M_2 < 1.13 m_Z = 103 \text{ GeV} \quad (9)$$

Using the program SUSYGEN [?], in which the sparticle masses are calculated more precisely [?], we find a similar bound of 104 GeV.

The condition (5) is more difficult to understand, since two more MSSM parameters come into play: m_0 , which determines the sneutrino mass, and the higgsino mass parameter μ , appearing in the neutralino mass matrix. Using the basis for the interaction eigenstates as given in reference [?], the mass matrix becomes

$$\begin{pmatrix} 0.61 M_2 & 0.21 M_2 & 0 & 0 \\ 0.21 M_2 & 0.88 M_2 & m_Z & 0 \\ 0 & m_Z & \mu \sin 2\beta & -\mu \cos 2\beta \\ 0 & 0 & -\mu \cos 2\beta & -\mu \sin 2\beta \end{pmatrix} \quad (10)$$

Here the GUT gaugino mass relations and the numerical value for the weak mixing angle have been used.

The smallest eigenvalue, the neutralino mass $m_{\tilde{\chi}_1^0}$, can become large only if both M_2 **and** $|\mu|$ are large. Equation (9) therefore implies an upper bound on $m_{\tilde{\chi}_1^0}$ and, through (5), on $m_{\tilde{\nu}}$, of the order of m_Z .

After these qualitative arguments we need to determine the upper limit on the LSP sneutrino mass quantitatively. We computed $m_{\tilde{\nu}}$ for many points in the MSSM parameter space and calculated the maximum mass value from the subset of points which respect (4) and (5).

First we used the mass formulae as given above and diagonalised the neutralino mass matrix numerically. The parameter space was scanned in the range $0 < M_2 < 110 \text{ GeV}$, $0 < m_0 < 1000 \text{ GeV}$, $\pm\mu < 1000 \text{ GeV}$, $1 < \tan\beta < 50$. The characteristic value of 1000 GeV is motivated by the requirement that SUSY solves the hierarchy problem. More than 1 billion points have been considered. Result: $m_{\tilde{\nu}}^{LSP} < 44.3 \text{ GeV}$.

We repeated the procedure with SUSYGEN, which is more precise but less fast. In order to save computer time, we scanned only through that subset of the MSSM parameters for which the approximate formulae predict high values of $m_{\tilde{\nu}}^{LSP}$. The step sizes were 0.1 GeV in M_2 and m_0 , 0.1 in $\tan\beta$ and 5 GeV in μ (on which the sneutrino mass depends only indirectly). The resulting theoretical upper limit is

$$m_{\tilde{\nu}}^{LSP} < 44.2 \text{ GeV} \quad (11)$$

in good agreement with the approximate value of 44.3 GeV. The corresponding MSSM parameters are $M_2 = 84.1 \text{ GeV}$, $m_0 \rightarrow 0$, $\tan\beta = 4.2$ and $\mu \approx -190 \text{ GeV}$. The neutralino mass is nearly degenerate with the sneutrino mass in this case.

The difference between the experimental and theoretical limits on the sneutrino mass derived in this paper is rather small. Therefore the inclusion of higher order corrections both to the sneutrino contribution to the Z width as well as to the sparticle masses is desirable.

An improved experimental limit cannot be expected in the near future. The LEP I data taking and analyses are completed, and at LEP II the cross section for the relevant channel, $e^+e^- \rightarrow \tilde{\nu} \bar{\tilde{\nu}} \gamma$, is small.

Conclusions

LEP I data show that the sneutrino must be heavier than 44.6 GeV at the 95% confidence level. In the sneutrino LSP scenario this experimental lower bound is inconsistent with the theoretical upper limit on the sneutrino mass. Therefore - within the constrained MSSM - the sneutrino can **not** be the LSP!

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References